Atomic Parity Nonconservation in Stable Yb Isotopes

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The weak interaction, best known for its role in nuclear beta decay, also plays a minor role in the electronic structure of atoms. Atomic structure is dominated by the electromagnetic interaction, which conserves parity (mirror reflection symmetry), whereas the weak interaction does not. Measurement of parity nonconserving (PNC) effects in atoms allows one to observe the weak interaction in a system dominated by the electromagnetic interaction. The study of atomic PNC, which is due to the weak neutral current (Z-exchange), complements the study of nuclear beta decay, which results from the weak charged current (W-exchange).

The $(6s^2)^1S_0 \rightarrow (6s5d)^3D_1$ transition in atomic Yb is a promising system for the study of PNC[1]. The E1 transition amplitude is strictly forbidden by the parity selection rule, while the M1 amplitude is highly suppressed.The application of an external electric field mixes even and odd parity states, giving rise to a Stark-induced amplitude ($E1_{st}$). The weak interaction also mixes even and odd parity states, giving rise to a parity nonconserving amplitude ($E1_{PNC}$). In order to measure a very small $E1_{PNC}$, one observes the interference between the much larger $E1_{st}$ and $E1_{PNC}$, as one excites this forbidden transition with intense laser light. The parity violating effect in Yb is expected to be very large, due to the near degeneracy of two states of nominal opposite parity .

Precise measurements of PNC in single isotopes of Cs[2] and Tl[3], when combined with atomic structure calculations, have led to a determination of the weak mixing angle ($\sin^2\theta_W$), rivaling those obtained from high energy physics experiments. Measurement of PNC in a single isotope of Yb will not be competitive with Cs or Tl, because the uncertainty in the calculation of the atomic structure of Yb is large. However, Yb has seven stable isotopes. The dominant contribution to atomic PNC comes from the electron-nucleon interaction, and one expects the effect to be roughly proportional to the neutron number, N. Comparing PNC effects in several isotopes of Yb may allow us to extract information about the weak interaction independent of the atomic structure. The PNC effect for a given isotope also depends on the distribution of neutrons within the nucleus, a nuclear property not readily accessible by other means. In addition, comparison of PNC effects in the different hyperfine components of the two odd A isotopes of Yb allows a determination of the nuclear anapole moment.

The past year has seen the publication of Yb lifetime measurements[4] and the first observation of the forbidden transition used in the study of PNC in Yb, as shown in Fig. 1.

Footnotes and References

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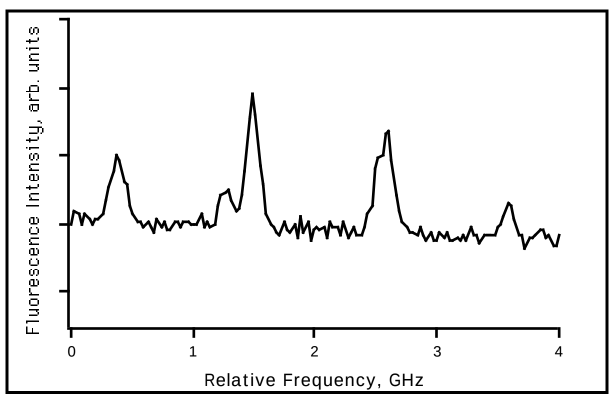

Fig. 1. Fluorescence signal from the forbidden M1 transition in ytterbium in a 45 kV/cm electric field. The peaks correspond to individual isotopes and hyperfine components.